Discussions on Disposal Forms of Auxiliary Heat Source in Surface Water Heat Pump System

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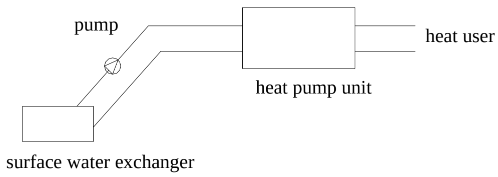
Abstract: This paper presents two common forms of auxiliary heat source in surface water heat pump system and puts forward the idea that the disposal forms affect operation cost. It deduces operation cost per hour of the two forms. With a project calculation, it illuminates that the post-located auxiliary heat source cheaper and superior to the fore-located one.

Key words: surface water heat pump, auxiliary heat source, operation cost

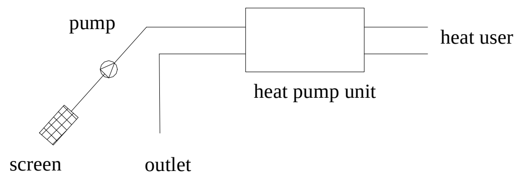
1 INTRODUCTION

Surface water heat pump system (SWHPS) is a heating and cooling system which uses the surface water as the heat source. When surface water is enough near the building, the heat can be transferred to heat pump unit from surface water in winter or the heat to surface water from heat pump unit in summer. SWHPS can be classified as two types, open system and close system [1-3], as shown in Fig.1. The efficiency of open system is higher than close one, and is applied in the big system, but it has the dirt problem, which needs to be cleaned regularly.

Under the heating condition in the cold area, the temperature of the surface water should be above 0℃ after heat transfer for fear freezing and cramming. So the auxiliary heat source is often necessary at heating peak load, and it has two forms, fore-located and post-located, as shown in Fig.2. Actually, some projects do not think about where auxiliary heat source should be put so as to increase the operating cost sometimes [4]. This paper will analyze it.



a) Close system



b) Open system

Fig.1 The types of system

2 COMPARE ON OPERATING COST OF TWO DISPOSAL FORMS

In two disposal forms of the auxiliary heat source, the parameters in the side of surface water and heat user (the temperature and flux of the inlet or outlet water) are the same.

The heat load of heat user is

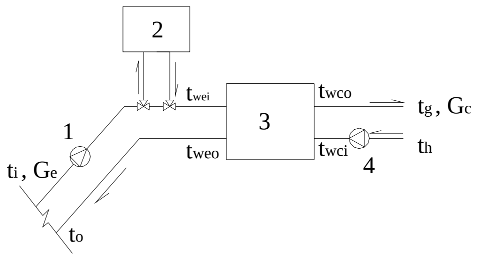
$$Q = CG_c\left(t_g - t_h\right) \tag{1}$$

where Q is the heat load, t_g and t_h are the temperature of the inlet and outlet water to heat user, and G_c is the flux of the heat water.

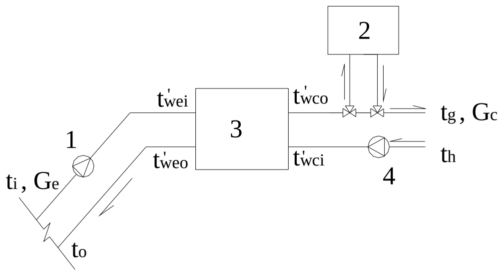
The quantity of heat acquired from the surface water is

$$Q_w = CG_e\left(t_i - t_o\right) \tag{2}$$

where Q_w is the quantity of heat from the surface water, C is specific heat, t_i and t_o are the inlet and outlet surface temperature , and G_e is the flux of the surface water.



a) The fore-located auxiliary heat source



b) The post-located auxiliary heat source

Fig. 2 Dispositional types of auxiliary heat source

1 cold water pump 2 auxiliary heat source

3 Heat pump system 4 hot water pump

2.1 Fore-located Auxiliary Heat Source System

For the fore-located auxiliary heat source, the heat from the auxiliary heat source is

$$Q_a = CG_e\left(t_{wei} - t_i\right) \quad (3)$$

where Q_a is heat acquired from the auxiliary he at source, and t_{wei} is the inlet water temperatur e in the evaporator.

The heat acquired by the evaporator is

$$Q_e = CG_e\left(t_{wei} - t_{weo}\right) \quad (4)$$

where Q_e is the quantity of heat acquired by the evaporator, and t_{weo} is the temperature of the outlet water in the evaporator.

The heat discharged by the condenser is that heat user needed,

$$Q = Q_{hp} = \frac{COP}{COP-1}Q_e$$
$$= CG_e\left(t_{wei} - t_{weo}\right)\frac{COP}{COP-1} \quad (5)$$

where Q_{hp} is the heat discharged by the condenser.

The power consumed in the heat pump system is

$$N_{hp} = \frac{Q_e}{COP-1} = C\frac{G_e\left(t_{wei} - t_{weo}\right)}{COP-1} \quad (6)$$

where N_{hp} is power consumed in the heat pump system.

The powers consumed by the pump on the side of the surface water or the heat user are, respectively

$$N_e = \rho g\frac{H_e G_e}{\eta_1} \quad (7)$$

$$N_c = \rho g\frac{H_c G_c}{\eta_2} \quad (8)$$

where N_e, N_c are the power consumed by the cold water pump or the hot water pump, H_e, H_c are pressure head in the side of the surface water source or the heat user, and η_1, η_2 are the efficiency of the cold water pump or the hot water pump.

The total power consumed of system is

$$N = N_{hp} + N_e + N_c \quad (9)$$

where N where the total power consumed in system.

So fore-located auxiliary heat source system's operating cost per hour is

$$F = N \cdot P_e + Q_a \cdot P_a =$$
$$P_e\left[\frac{CG_e\left(t_{wei} - t_{weo}\right)}{COP-1} + \rho g \cdot\right.$$
$$\left.\left(\frac{H_e G_e}{\eta_1} + \frac{H_c G_c}{\eta_2}\right)\right] + CP_a G_e\left(t_{wei} - t_i\right) \quad (10)$$

where F is the operating cost per hour, P_e is the price of the electric, P_a is the price of fuel offering 1kWh.

2.2 Post-located Auxiliary Heat Source System

For the post-located auxiliary heat source system, heat from surface water is

$$Q_w^{'} = Q_e^{'} = CG_e\left(t_{wei}^{'} - t_{weo}^{'}\right) \quad (11)$$

where the parameters have superscript:’.

The heat of auxiliary heat source is

$$Q_a^{'} = CG_c\left(t_g - t_{wco}^{'}\right) \quad (12)$$

The heat of condenser is

$$Q_{hp}^{'} = \frac{COP^{'}}{COP^{'}-1}Q_e^{'}$$

$$= CG_e\left(t_{wei}^{'} - t_{weo}^{'}\right)\frac{COP^{'}}{COP^{'}-1} \quad (13)$$

The power of heat pump is

$$N_{hp}^{'} = \frac{Q_e^{'}}{COP^{'}-1} = \frac{CG_e\left(t_{wei}^{'} - t_{weo}^{'}\right)}{COP^{'}-1} \quad (14)$$

The power of cold water pump of water is

$$N_e^{'} = \rho g\frac{H_e^{'}G_e}{\eta_1^{'}} \quad (15)$$

The power of hot water pump is

$$N_c^{'} = \rho g\frac{H_c^{'}G_c}{\eta_2^{'}} \quad (16)$$

The overall power of system is

$$N^{'} = N_{hp}^{'} + N_e^{'} + N_c^{'} \quad (17)$$

So fore-located auxiliary heat source system’s operating cost per hour is

$$F^{'} = N^{'}\cdot P_e + Q_a^{'}\cdot P_a =$$

$$P_e\left[\frac{CG_e\left(t_{wei}^{'} - t_{weo}^{'}\right)}{COP^{'}-1} + \rho g\cdot\left(\frac{H_e^{'}G_e}{\eta_1^{'}} + \frac{H_c^{'}G_c}{\eta_2^{'}}\right)\right] + CP_aG_e\left(t_g - t_{wco}^{'}\right) \quad (18)$$

2.3 Economical Compare

For specific heat pump unit, when the both side flux of evaporator and condenser are constant, its *COP* changes just with the outlet water temperatures of the evaporator and condenser, and COP is a function of t_{wco} and t_{weo},

$$COP = f\left(t_{weo}, t_{wco}\right) \quad (19)$$

Outlet water temperatures meet

$$t_i = t_{wei}^{'} \quad (20)$$

$$t_o = t_{weo} = t_{weo}^{'} \quad (21)$$

$$t_g = t_{wco} > t_{wco}^{'} \quad (22)$$

$$t_h = t_{wci} = t_{wci}^{'} \quad (23)$$

So we can know from these equations,

$$COP > COP' \quad (24)$$

The difference of operating cost per hour of fore-located and post-located auxiliary heat source system is

$$\Delta F = \left(N - N^{'}\right)\cdot P_e + \left(Q_a - Q_a^{'}\right)\cdot P_a \quad (25)$$

where $R = \frac{P_a}{P_e}$ is namely electrical price ratio which is shown in Fig.3 at basic data as the tab.1, and we get the difference of operating cost per hour ΔF is

$$\Delta F = CG_eP_e\left(1-R\right)\left(\frac{t_{wei}-t_o}{COP-1} - \frac{t_i - t_o}{COP^{'}-1}\right)$$

$$+\rho g\left[G_e\left(\frac{H_e}{\eta_1} - \frac{H_e^{'}}{\eta_1^{'}}\right) + G_c\left(\frac{H_c}{\eta_2} - \frac{H_c^{'}}{\eta_2^{'}}\right)\right] \quad (26)$$

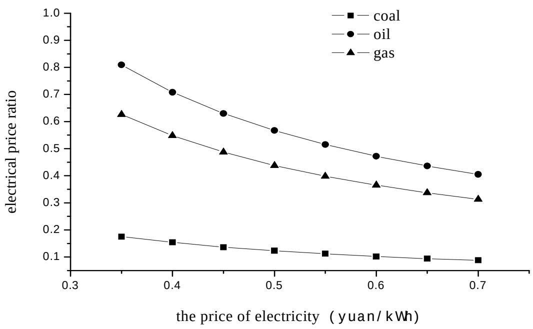


Fig.3 Electrical price ratio

Tab. 1 Basic data of fuel

Fuel	Price	Low grade calorific value	Boiler efficiency
coal	0.35 Yuan/Kg	29307 KJ/Kg	0.70
oil	2.8 Yuan/ Kg	41860 KJ/Kg	0.85
gas	1.8 Yuan/m^3	33600 KJ/m^3	0.88

In fore-located or post-located auxiliary heat source systems, the powers of cold or hot water pump in overall are small. When ignoring them, formula (26) can be written as

$$\Delta F = CG_e P_e (1-R)\left(\frac{t_{wei}-t_o}{COP-1}-\frac{t_i-t_o}{COP^{'}-1}\right) \quad (27)$$

So we get

$$\Delta F = \begin{cases} =0, & R=1 \\ >0, & R<1 \end{cases}$$

If electricity used as auxiliary heat source, the two disposal forms run same operating cost, else the fore-located form is cheaper.

3 EXAMPLE

Some construction is 15 thousand square meters, which uses surface water heat pump with oil boiler auxiliary heat source. Its design heat load is 1 MW, supply and return water temperature are 45 and 40 ,and design flux is 47.8Kg/s. On surface water side, design water temperature are 8 and 2 and design flux is 28.9Kg/s. auxiliary heat source begin to run under inlet surface water temperature is 8 for 60 days when average temperature is 4 . And given electricity price is 0.5 Yuan / kWh. Results are shown in tab.2.

We can know from table 2 that operating cost of fore-located auxiliary heat source is cheaper than the latter, and the difference is 41.3 Yuan / h. In the whole heating period, the difference is 59471 Yuan, namely 3.96 Yuan / m^2.

Tab. 2 Results of example

	fore-located	Post -located
Average COP	3.63	3.84
heat load of surface water (kW)	241.5	241.5
heat load of heat pump unit	1000	323
power of heat pump unit(kW)	275.5	84.1
auxiliary heat(kW)	483.2	677
ΔF (Yuan/h)	41.3Yuan/h	

4 CONCLUSIONS

Though the deduction and analysis, in practicable project, when adopting coal and oil and natural gas, we should adopt fore-located auxiliary heat source.

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